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BILATERAL ROBOT HAND BASED ON ESTIMATED FORCE FEEDBACK

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ABSTRACT

A novel approach to the bilateral motion is realized in the master-slave robot hand system. In the approach, there are neither force sensors nor tactile sensors in the slave hand. The contact force of the slave hand is estimated by the disturbance observer in the microprocessor-based controller. The estimated force is calculated from the velocity and the current of the slave hand for the feedback to the master hand in order that the operator feels the touch quality of the object grasped by the slave hand to some extent. The position reference of the slave hand is given through the master position. These two cross feedback loops are implemented in one microprocessor. The above algorithm is tested in two similar robot hands. The obtained results show the sufficient performance of the bilateral motion.

1. INTRODUCTION

A bilateral robot hand is suitable for the manipulations of the object particularly in the dangerous or the poor environment. For the fine control and the smooth operation, the force sensor or the tactile sensor are often attached on the surface of the slave hand.[1,2] However not only these sensors are precious but also they often require much signal processing.[3] Moreover, they are sometimes quite sensitive to the environmental change.

This paper proposes a novel approach to the control of the bilateral master-slave robot hand, where such a touch sensor is omitted in the slave hand. Instead of the touch sensors, the reactive force is estimated by the disturbance observer. As the necessary informations of the disturbance observer are only the armature current and the velocity of the slave hand which are easily measured without any special sensors but ordinal servo sensors, the proposed method is robust against the inferior environments. In addition to this robustness, the proposed method requires less computational effort to estimate the reactive force.

There are several ways to realize the bilateral servo systems.[4] The proposed strategy is basically applicable to any types of the master-slave systems, however, in the paper the above system is realized in the pair of similar one-degree-of-freedom robot hands and is tested. For the multi-degrees-of-freedom manipulator systems, although a little modification is necessary, the basic strategy is common. The operator feels well the touch quality according to the slave motion and consequently controls it successfully. To improve this touch quality, the frictions of the master side should be compensated in the controller. If the master hand is not same as the slave hand, this compensation is sometimes unnecessary. For example this case is realized when the master is a joy stick. Some experimental results when the proposed system is applied to the symmetrical bilateral robot hands are shown in this paper. However the disturbance observer is also applicable in an asymmetrical case.

2. STATE OBSERVER TO ESTIMATE DISTURBANCE

The disturbance observer estimates the total sum of the disturbance torque. As it depends on the structure of the motor, the model of the actuator should be considered. The servo motor as an actuator is represented in the block diagram as shown in Fig. 1. The armature current is directly controlled by the current minor feedback loop. This results the simplified motor model as shown in Fig. 2.
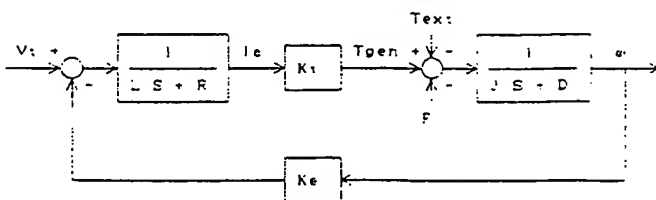

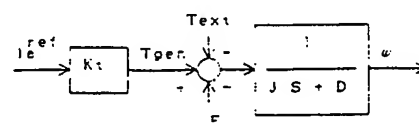Figure 1. Block diagram of a dc servo motor

Figure 2. Simplified block diagram of a controlled dc servo motor

Here:

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Vt    = terminal voltage
Ia    = armature current
L     = armature inductance
R     = armature resistance
Kt    = torque constant
Ke    = counter e.m.f. constant
Tgen  = generated motor torque
Text  = reactive force and external force
J     = inertia
D     = damping coefficient
F     = coulomb friction
ω     = rotor speed
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and the upper suffix ref denotes reference value and the lower suffix n denotes nominal value. By measuring the current and the velocity, the simple calculation represented in the hatched block diagram of Fig.3 brings the following result.

$$Tdis = Text + (J-Jn)S\omega + (D-Dn)\omega + F \tag{1}$$

The first term is the external torque. The second is the varied self-inertia torque. The third is the varied viscosity and the forth is the coulomb friction. When Fig.3 is applied to the slave hand, the force for the feedback to the master controller is obtained by removing the second, the third and the forth terms. This is explained closely in the later chapters. It is difficult to realize Fig.3 due to the pure differentiation of the velocity signal. The disturbance observer is constructed so as to suppress the unnecessary high frequency area where the noise is the main component. The obtained observer is shown in Fig.4, where g is the cut-off angular frequency to inhibit the pass of the high frequency.
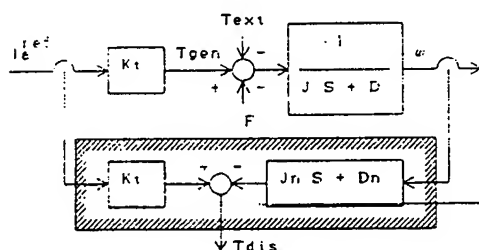

Figure 3. Calculation of
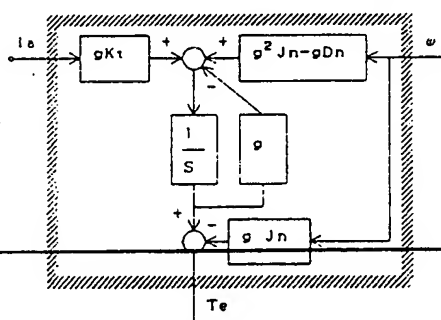the disturbance torque

Figure 4. Block diagram of
the disturbance observer

The obtained output Te, is represented as follows,

$$Te = \frac{1}{1 + \frac{1}{g}S} \; Tdis. \tag{2}$$

Eq.(2) shows that the estimated disturbance torque is almost the same as the disturbance torque, if g is chosen as large as possible. According to the former researches,[5,6] g is chosen more than from 500(rad/sec) to 5000(rad/sec), that is large enough to regard the estimated torque as the disturbance torque.

3. BILATERAL ROBOT HAND SYSTEM

There are several methods to realize the bilateral servo system.[4] In the paper, the force feedback system shown in Fig.5 is applied to the master-slave robot hands. Here the position of the master hand gives the position reference of the slave hand. The error between the position of the master hand and the slave hand drives the motor of the slave hand so as to decrease this error. The reaction torque except the effect of the coulomb friction is estimated by the observer where only the armature current and the rotor speed of the slave motor are used. The estimated reaction torque drives the motor in order that the operator feels the touch quality. In this bilateral hand system, the inertia and the viscosity of the slave does not change according to its position and attitude. As they are constant and are able to be treated as fixed nominal values, the observer estimates only the sum of the external force and the coulomb friction. This is resulted from eq.(1) and (2) by substituting Jn and Dn into J and D espectively. The external force is obtained by subtracting the coulomb friction F from the estimated

disturbance. According to the measured results of the coulomb friction, F is represented as the sum of constant part and the proportional part depending on the normal force. Therefore estimated reaction torque of the slave hand is given as,

$$Text = (1-n)(Te-Fo) \qquad (3)$$

where n is the proportional constant between 0 and 1 and Fo is the constant part of the coulomb friction and its sign depends on the moving direction. This final result drives the master motor to generate the reaction force of the slave hand in the master side. To obtain high sensitivity of the touch quality in the master side, it is necessary to compensate the friction of the master hand. For that purpose, the master motor should generate the following torques,

$$Tm = Thand + Jt \frac{d\omega m}{dt} + Dm\omega m + Fm. \qquad (4)$$

Here Thand is the operator's force and lower suffix m represents the master side. If the generated torque of the master motor is equal to sum of the estimated reactive torque of the slave hand and the friction of the master hand, then the operator feels well the reaction torque of the slave hand. Consequently the master motor should support,

$$Tm = AText + Dm\omega m + Fm. \qquad (5)$$

Here A is the adjustment factor of the feeling and is determined according to the sensitivity of the touch quality. The voltage command of the master motor is

$$Vm = \frac{R}{Kt} \; Tm + kem\omega m. \qquad (6)$$

In case the current source is adopted, the current command of the master motor is

$$Im = \frac{1}{Kt} \; (AText + Dm\omega m + Fm) \qquad (7)$$

The compensation of the frictions of the master hand makes the sensitivity of the touch quality higher. In the later experiment the master hand and the slave hand is similar and adjustment factor is chosen as 1.0.
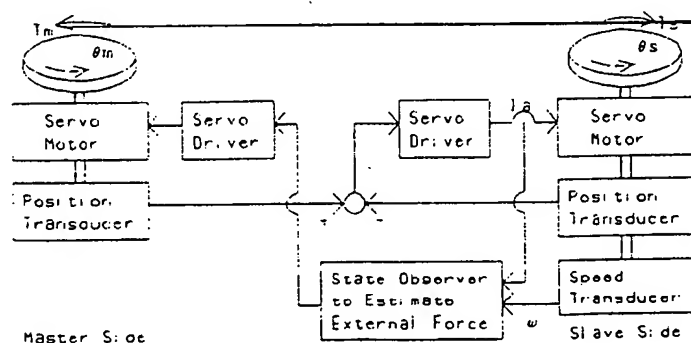

Figure 5. Master slave bilateral servo system based on the estimated force feedback.

4. EXPERIMENTAL SYSTEM

The experimental system is set up to verify the proposed system. The schematic diagram of the experimental robot hand is shown in Fig.6. As shown in Fig.6, the calculation process of the disturbance observer, and the compensation of the friction effects in the both hands are carried out in one microprocessor. Also the position control of the slave hand is executed in the same processor. The proposed system is applied to the similar twin robot hand which has one-degree-of-freedom. Fig.7 shows one robot hand to be controlled. The approach motion of the gripper is driven by the dc servo motor through the ball screw, which is symmetrical at the middle point. Therefore, the two nuts move oppositely each other and that enables to open and close the robot hands. And the gravity force does not influence the estimated torque because of this mechanical structure. The lead of the ball screw is 4mm/r. The dc servo motor, the tachogenerator and the optical encoder are directly nected to the ball screw. The measured and calculated parameters are shown in Table.1. the control steps are carried out in one 16 bit microprocessor, whose sampling rate is 1.54 msec. The digital pole of the disturbance observer is determined as 0.5.
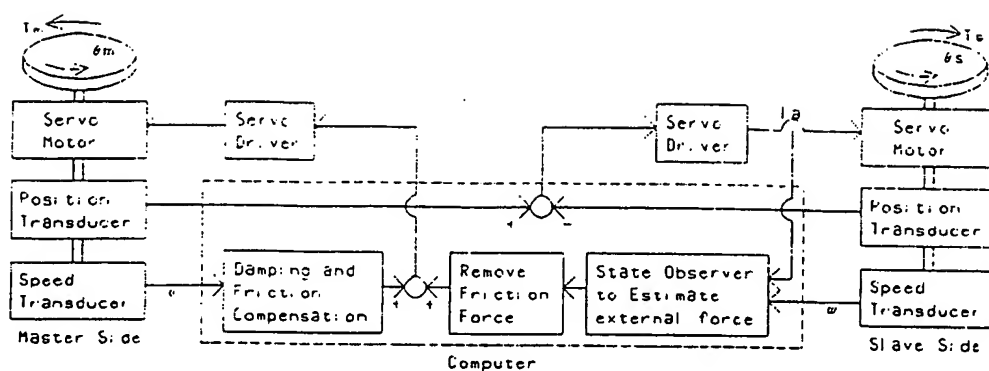
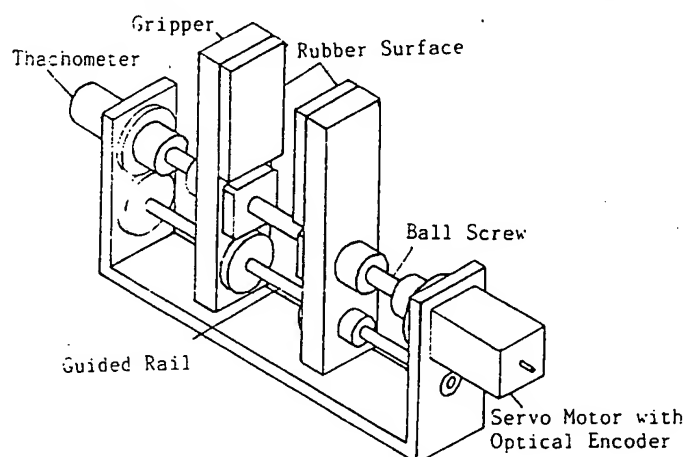Figure 6. Experimental bilateral servo system

Figure 7. Bilateral robot hand

Table 1. Parameters of Experimental Robot Hand

rated output		22 W
rated speed		2000 r.p.m.
rated current		0.97 A
L		8 mH
R		20 Ω
Kt		1.36 Kg-cm/A
Ke		13.9 V/K.r.p.m.
Jn		0.1043 Kg-cm²
Dn	(master)	9.29X10⁻³ Kg-cm/r.p.s.
	(slave)	11.32X10⁻³ Kg-cm/r.p.s.
F	(master)	0.150 Kg-cm
	(slave)	0.231 Kg-cm

5. EXPERIMENTAL RESULTS

5.1. Position control of slave hand

At first the position servo characteristics are tested in the master-slave bilateral system. Fig. 8 shows the time response of the slave hand which is controlled to track the master hand movement.
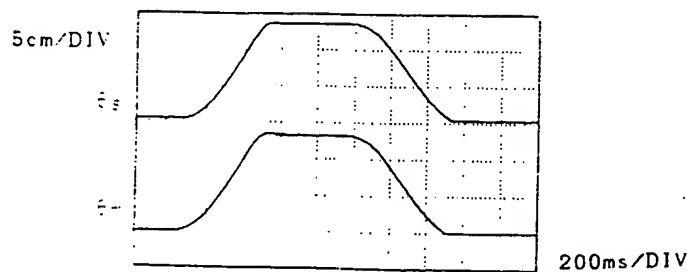
5cm/DIV

200ms/DIV

Figure 8. Time response of the slave hand by the movement of the master hand

5.2. Output of the state observer

The output of the observer is shown in Fig. 9 when the slave hand grasps the load-cell. The horizontal axis shows the measured pressure P and the vertical axis shows the output of of the observer. The upper line is measured when the pressure is increasing and the lower is measured when the pressure is decreasing. This relation is linearized when the friction force of the slave is compensated. The compensated result is shown in Fig. 10.
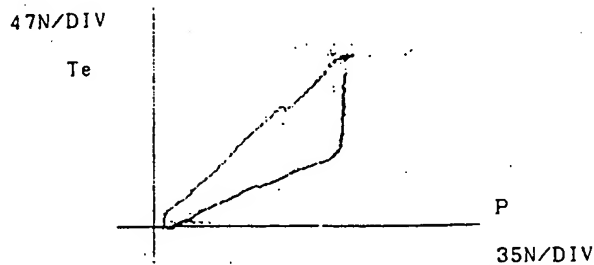
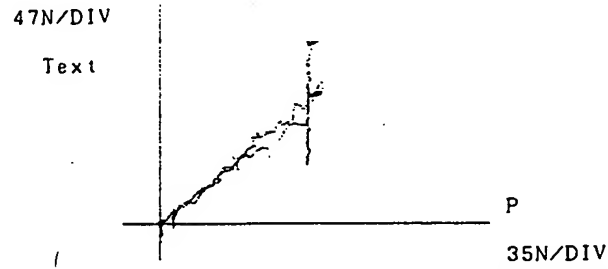Figure 9. Relation between the pressure of the hand and the estimated torque

Figure 10. Relation between the pressure of the hand and the estimated torque after the removal of coulomb friction

This compensation seems effective except the speed of the rotor is zero, because the moving direction of the slave hand is not determined at that point. The right side line in Fig. 10 shows this undetermined point. This is compensated by inserting the weighting factor which depends on the rotor speed in the friction compensation process. Fig. 11 shows the time response example of the observer output after above compensation. The estimated torque well coincides with the measured imposed force.
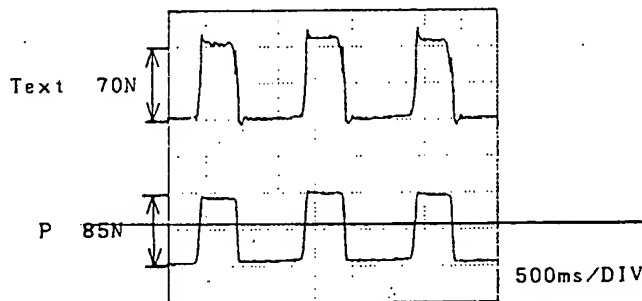
Figure 11. Time response of the measured force and the calculated torque

5.3. Friction and damping compensation of the master hand

For the reduction of the operator's physical effort, it is effective to compensate the friction of the master hand. This compensation is based on eq. (5). The experimental results to move the master hand are shown in Fig. 12.
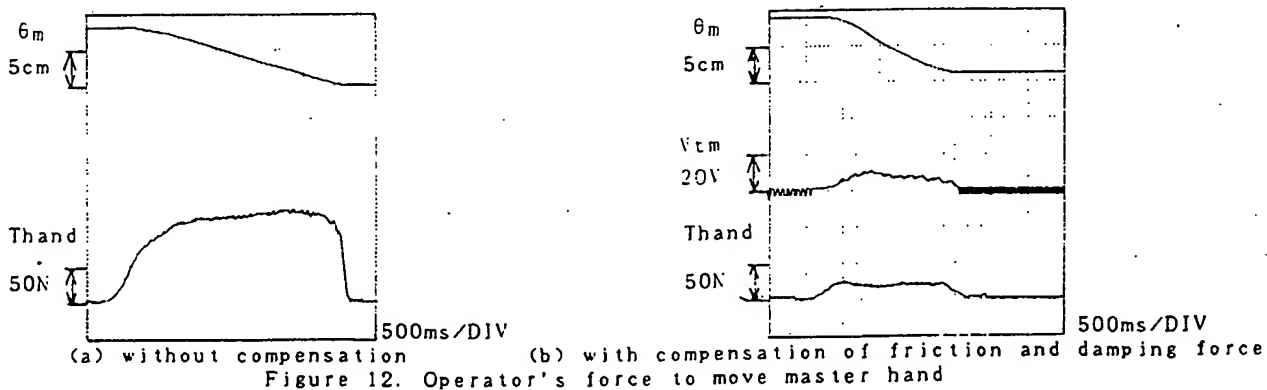
(a) without compensation

(b) with compensation of friction and damping force

Figure 12. Operator's force to move master hand

Fig. 12 (a), as any compensations of master hand are not carried out, the required torque move the mater hand is very large. The compensation based on eq. (5) makes the master hand to move smoothly. Fig. 12 (b) shows the compensated effect. The required torque to move the master hand is reduced and the smooth operation is required.

5.4. Gripping the object

The proposed algorithm is implemented in the experimental robot hand and is tested. Fig. 13 (a) shows the result when the slave hand grips the soft object. Fig.13 (b) shows that the slave hand grasps the hard object. In both cases, after grasping the object, the operator imposes his force four times.

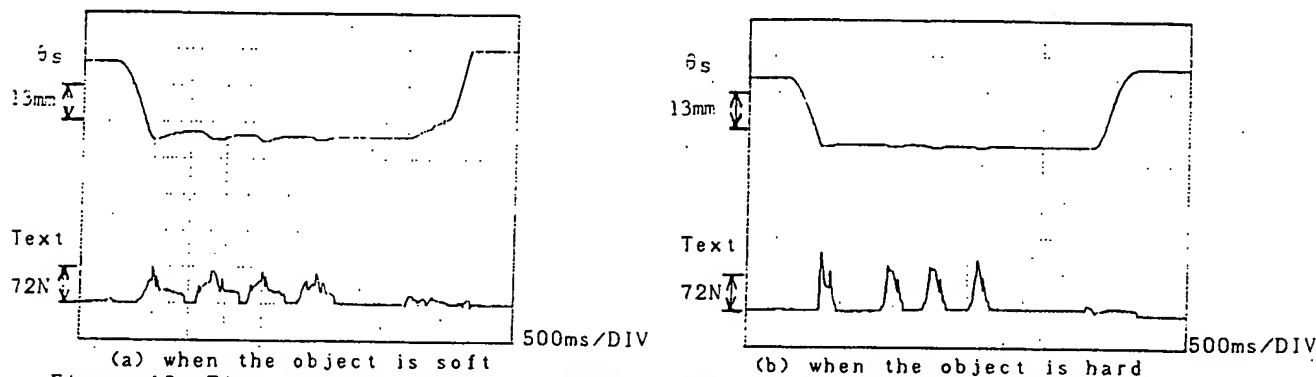(a) when the object is soft (b) when the object is hard
Figure 13. Time response of the estimated torque when the slave hand grasps an object

The operator feels well the touch quality in both cases. The proposed bilateral master-slave system works well in the experimental system.

6. CONCLUSIONS

Through a set of experiments, it is confirmed that the state observer is effective to detect the external force. A bilateral servo system based on the estimated force feedback is able to be implemented without the pressure sensor and is successfully applied to the master-slave robot hand. This proposed method is also expected to be expanded to more advanced robotic system.

7. REFERENCES

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